Essay

Benefits of macroalgal blooms for the production of biofertilizers

Martin F. Soto-Jimenez[1§]
María Julia Ochoa-Izaguirre[2]
Elsa I. Bojorquez-Mascareño[1]

[1]Institute of Marine Sciences and Limnology-National Autonomous University of Mexico. Walkway of the Azada s/n, Centro, Mazatlán, Mexico. [2]Faculty of Marine Sciences-Autonomous University of Sinaloa. Claussen promenade s/n, Col. Los Pinos, Mazatlán, Sinaloa, Mexico. CP. 80000. (mochoa@uas.edu.mx; aidet-sinaloa@yahoo.com).

[§]Corresponding author: martin@ola.icmyl.unam.mx.

Abstract

In the present essay, an alternative for the production of biofertilizers is proposed based on the use of macroalgal blooms that are occurring in the coastal lagoons of Sinaloa. Coastal communities can obtain an economic benefit by properly harvesting part of the biomass resulting from such blooms. The extracted macroalgal biomass could be used to produce biofertilizers, with the following benefits: a) mitigate the ecological damage caused by macroalgal blooms to eutrophicized coastal ecosystems; b) the use of organic fertilizers in agricultural fields allows N and P to be recycled, thus avoiding the application of more synthetic fertilizers, which are primarily responsible for macroalgal blooms; c) in addition to containing biofertilizers based on macroalgae, N and P contain a set of micronutrients and substances with the potential to benefit crops and improve soils; d) it contributes to carbon sequestration and the reduction of greenhouse gases in the atmosphere; and e) economic benefits in the use of a raw material, nowadays, of low value or without commercial value. Such biofertilizers would be used to produce fruits and vegetables of the so-called organic, which have a high surplus value and their demand is increasing in Mexico and in the world. This is an alternative focused on the production of biofertilizers for use in organic agriculture and production of fruits of high economic value, which can be accredited as organic and at the same time, contribute to the improvement of soils and the state of health of coastal ecosystems

Keywords: coastal lagoons, eutrophication, organic agriculture, Sinaloa.

Reception date: August 2019
Acceptance date: October 2019

Use of synthetic fertilizers

After the chemists Carl Bosch and Fritz Haber developed the Haber-Bosch process, it was possible to synthesize ammonia (NH_3) in an industrial way, by reacting between molecular nitrogen (N_2) and methane (CH_4) at high temperatures and pressures. This process soon detonated the production of synthetic fertilizers, and associated with the production of pesticides, the development of irrigation systems and the technological advances for the mechanization of the crop, allowed an exponential growth in agriculture in the 1940.

With the so-called green revolution, agriculture went from being an artisanal and unproductive activity, to an intensive, highly mechanized and fertilized activity. Today, global cereal production is estimated at 2 498 million tons, with a fertilizer consumption of 186.9 million tons. In 2018, global demand for fertilizers was projected at 200.5 million tons: 60% N+23% P_2O_5+17% K_2O.

In Mexico, agriculture also experienced accelerated growth, driven by the increase in irrigated cultivated area, increased crop frequency and increased yields. Currently, agriculture is practiced in 32.41 million hectares, with 79% of temporary and 21% of irrigation (INEGI, 2017). Temporary agriculture is dependent on rainfall, allows one crop per year, is of low intensity, low production and less environmental impact. Irrigation agriculture uses an artificial irrigation system (by gravity or rolling, drip, spray), allows at least two crops per year, is highly mechanized and fertilized and of course, more productive, but with greater environmental impact. Fertilizer consumption in Mexico is estimated at about 4 million tons per year, with an annual growth rate of 3-5% (FAO, 2015).

According to Calderón-Salazar (2017), the Mexican countryside is not very competitive in the international context and does not allow food self-sufficiency; more than 80% of rice, 31% of corn and 65% of wheat consumed in Mexico is imported. The lack of competitiveness is due to the fact that in the last 35 years the infrastructure, technology, qualification of the workforce, organization of production, linking of markets and structuring of the financial system has lagged, coupled with the fact that the Treaty of North American Free Trade has been unfavorable for Mexican agriculture.

An explanation for the lack of competitiveness is the high cost of synthetic fertilizers that represent 60% in temporary crops and 30% in irrigation crops (Aguado-Santacruz, 2012; INEGI, 2017). In 2017, the list price of granulated fertilizers varied from $8 002.00 pesos per ton for granulated urea to $13 015.00 pesos per ton for ammonium nitrate, and liquid fertilizers of $7 831.00 pesos per ton for ammonium nitrate+urea to $10 750.00 pesos per ton for anhydrous ammonia (Secretaría de Fomento Agropecuario, 2018). More than 85% of the volume of fertilizers consumed are imported. According to the National Agricultural Survey (INEGI-SAGARPA, 2014), 75.7% of agricultural producers mention that the high costs of inputs and services are the main problem they face. Another problem is the loss of crops due to climatic and biological causes.

Environmental problems due to the use of synthetic fertilizers

In addition to the high cost of fertilizers, only between 20 and 40% of what is applied is used by crop plants and up to 60% evaporates into the atmosphere in gaseous emissions of ammonia, nitric oxide and nitrous, while 20% is drained to water bodies (ammonium, nitrates) or infiltrates the water table (nitrates) (GeoHab, 2006; Páez-Osuna *et al*., 2007; Howarth, 2008). The loss of nitrogen brings environmental pollution associated with the emission of greenhouse gases, with potential for acid rain, eutrophication of coastal ecosystems and pollution of groundwater with nitrates.

This pollution in turn results in negative effects on the health of people and ecosystems. One of the most serious environmental problems is the process known as coastal eutrophication, which is defined as an enrichment of nutrients in the water, especially nitrogen or phosphorus and organic matter, which results in the depletion of oxygen in the waters and anoxia conditions in the sediments, reduce water transparency, and generate disturbances in the biogeochemical cycles of C, N and P. Ecological effects of eutrophication include changes in the abundance and composition of the phytoplankton and macroalgal community, alterations in the quality and diversity of the habitat, mortality of fish and invertebrates, and variations in the structure of the food chain (GeoHab, 2006; Páez-Osuna *et al*., 2007; Canter, 2018).

Macroalgal blooms in coastal lagoons

The increase in the frequency and magnitude of macroalgal blooms in coastal systems around the world, such as coastal lagoons and estuaries, is considered the greatest environmental problem of marine environments (Valiela *et al*., 1997; Orth *et al*., 2006; Teichberg *et al*., 2010; Barbier *et al*., 2012). The coasts of Mexico have not been alien to this problem. Several scientific papers have documented the existence of environmental problems and the loss of water quality due to nutrient enrichment in the coastal zone (Soto-Jiménez *et al*., 2003a, 2003b; Páez-Osuna *et al*., 2007).

The increasingly frequent, intense and extensive episodes of red tides and macroalgae blooms are a consequence of increased eutrophication in coastal waters. Macroalgal blooms are recurrent in different coastal areas of Sinaloa at different times (Figure 1), derived from the excessive supply of nutrients from agricultural and livestock activities, urban and industrial waste, burning of fossil fuels, and the occurrence of natural leaching processes of soils (Piñón-Gimate *et al*., 2009; Ochoa-Izaguirre and Soto-Jiménez, 2013; 2015).

Macroalgal blooms stand out for the abundance of one or two species that displace other macroalgae species in the ecosystem, causing an imbalance in trophic networks and producing a series of ecological alterations. The detriment of water quality translates into negative consequences for biota and economic losses due to damage to fisheries of multiple species that use coastal environments as a breeding and rearing site. In addition, they result in loss of tourist attraction since undesirable odors occur during their decomposition and bad appearance in the places where they are generated and accumulated.

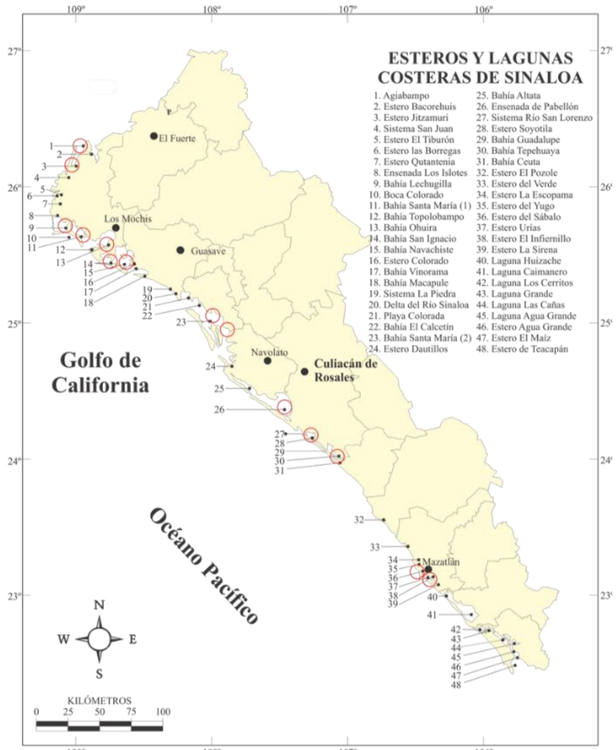

Figure 1. Bodies of coastal waters of Sinaloa with occurrence of macroalgal blooms observed in our routes (in red circle).

Benefits of macroalgae as biofertilizers

Macroalgae have been used for centuries as food and natural fertilizers in many coastal regions of the world (Zemke-White and Ohno, 1999; McHugh, 2003; Craigie, 2011; Wijesekara *et al*., 2011). The establishment of the Haber-Bosch process for the preparation of synthetic chemical fertilizers caused interest in these natural products to be lost. Currently, the use of organic fertilizers from algae has gained more interest because it has been observed that the value of macroalgae as fertilizers lies not only in their N and P content, but also because they include a wide range of essential trace elements (eg Ca, Mg, S and some trace elements such as B, Cu, Fe, Mn, Mo, and Zn), amino acids, vitamins, auxins and phytohormones of the cytokinin and gibberaline type, which improve the quality of the crops (Thirumaran *et al*., 2009; Khan *et al*., 2009; Kim, 2011; Kurepin *et al*., 2014; Seghetta *et al*., 2016).

Figure 2 schematizes the potential benefits of using biofertilizers in a typical tomato crop in Sinaloa. In summary, this organic supplement used as a basal fertilizer allows better seed germination, an increase in root development, a faster and more uniform stabilization plant, an increase in nutrient absorption, a more efficient exploitation of nutrients. In addition, it results in improvements in tissue composition, greater resistance to frost and drought and faster recovery, greater resistance to diseases, pests (by fungi and insects) and droughts, and a longer shelf life (Arioli *et al*., 2015; Du Jardin, 2015).

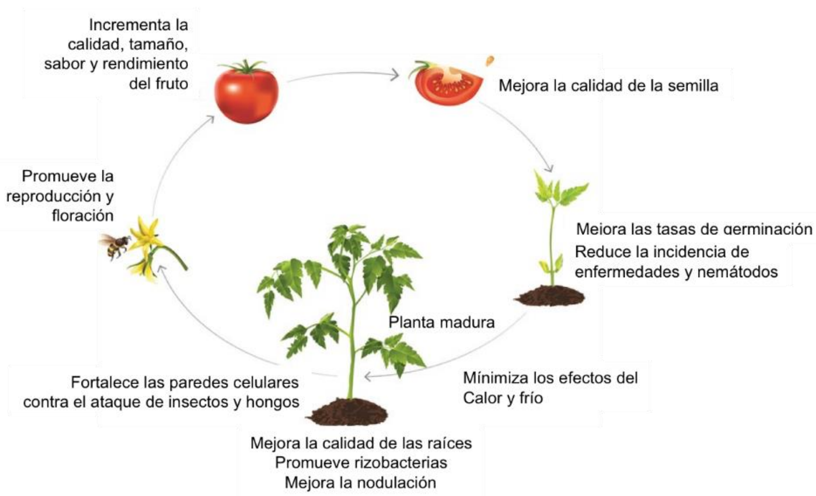

Figure 2. Schematization of the potential benefits of the use of biofertilizers in tomato cultivation in Sinaloa.

Macroalgae are biodegradable, non-toxic, non-polluting and do not represent any danger to humans, animals or birds; even in some countries of the East (China, Japan and Korea) they are highly consumed as human food (Hong *et al*., 2007). Based on this knowledge, it is possible to reduce the ecological damage caused to coastal ecosystems, taking advantage of the biomass of macroalgae and thus obtain an economic benefit by properly harvesting the biomass resulting from such blooms for use as organic fertilizers.

Another environmental benefit of using biofertilizers from macroalgae is its capacity for CO_2 sequestration and the consequent uptake of greenhouse gases from the atmosphere, this because it increases the natural capacities of the soil and crops for the sequestration of carbon, compared to synthetic fertilizer. On the other hand, the dependence on industrial nitrogen fixation and the burning of fossil fuels is reduced.

Advances in research in Mexico

Different researchers from the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) of SAGARPA and the Center for Genomic Biotechnology of the National Polytechnic Institute have contributed to the development of biofertilizers in Mexico. Most of its advances have been in the use of live microorganisms, which have been tested in different crops and in different regions of the country (Contreras-Cornejo *et al*., 2009; Aguirre-Medina *et al*., 2009; Grageda-Cabrera *et al*., 2012; Aguado-Santacruz, 2012; Zermeño-González, 2015). The first studies of the potential use of macroalgae as biofertilizers in Mexico were carried out at the Antonio Narro Autonomous Agrarian University since the 1980s, in collaboration with the company Palau Bioquim, SA de CV (Canales-López, 1997; 2000). After years of observations, studies and research, experiments and tests, in 1990 it was finally possible to have the first commercial product based on seaweed extract in Mexico ALGAENZIMS[MR] (http://www.palaubioquim.com.mx).

More recently, researchers from the University Center of Biological and Agricultural Sciences of the University of Guadalajara, Interdisciplinary Center of Marine Sciences of the National Polytechnic Institute, in collaboration with the Canadian company Acadian Seaplants Limited, have conducted various tests with extracts of different species of macroalgae that they include *Ulva lactuca*, *Caulerpa sertularioides*, *Padina gymnospora* and *Sargassum liebmannii* as biostimulant of germination and growth of tomato (*Solanum lycopersicum*) and bean plants (Hernández-Herrera *et al*., 2014, 2016; Castellanos-Barriga *et al*., 2017).

Regarding the progress of our investigations, we have focused on assessing the potential of macroalgal blooms in the coastal lagoons of Sinaloa for the development of biofertilizers. To date, we have collected information on the formation of macroalgal blooms, the sites and times of appearance, their biomass and variations over time. Nine species of flowering-forming macroalgae have been identified: *Ulva expansa*, *U. lobata*, *U. intestinalis*, *U. clathrata*, *Codium amplivesiculatum*, *Caulerpa sertularioides*, *Gracilaria vermiculophylla*, *Spyridia filamentosa* and *Cladophora* sp.

The ecosystems associated with the agricultural valleys of Fuerte and Guasave and the urban area of Mazatlán are the most affected. The photographs shown in Figures 3 and 4 give evidence of macroalgal blooms of various species in different coastal ecosystems of Sinaloa. The species *Spyridia filamentosa* and *Codium amplivesiculatum* stand out in an estuary of the Lagunar Ohuira-Topolobampo Complex, the flowering of *Codium amplivesiculatum* and the arrival of *Cladophora* sp., in the Lagunar Navachiste System, and the blooms of *Ulva clathrata* and *Gracilaria vermicroophylla* in the Estero de Urias, in Mazatlán.

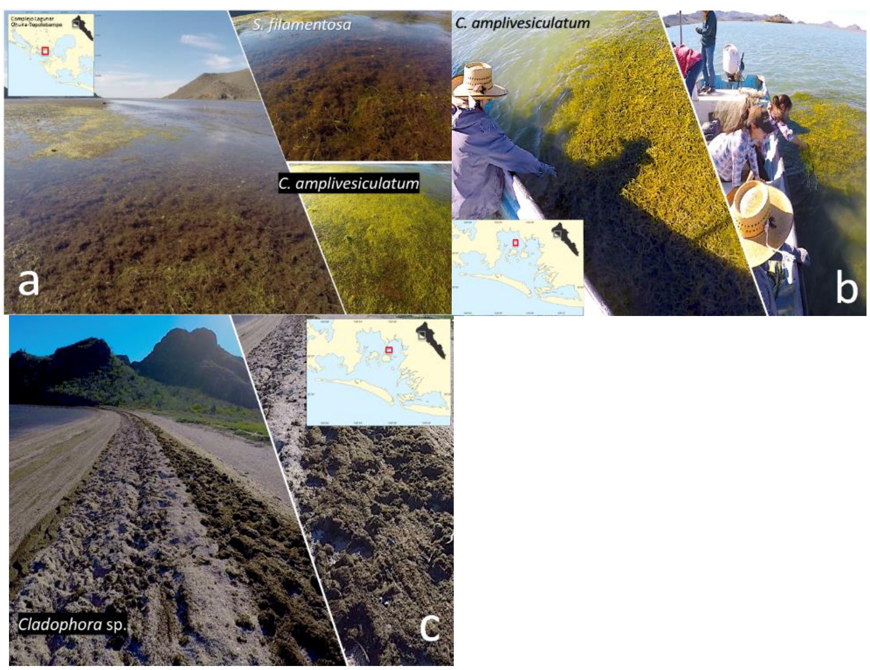

Figure 3. Flowering species. a) *Spyridia filamentosa* and *Codium amplivesiculatum* on an estuary of the Lagunar Ohuira-Topolobampo Complex, in Ahome, Sinaloa (March 2017); b) *Codium amplivesiculatum* in the Lagunar Navachiste System, in Guasave, Sinaloa (March, 2017); and c) arrival of *Cladophora* sp. in the Lagunar Navachiste System, in Guasave, Sinaloa (March, 2017).

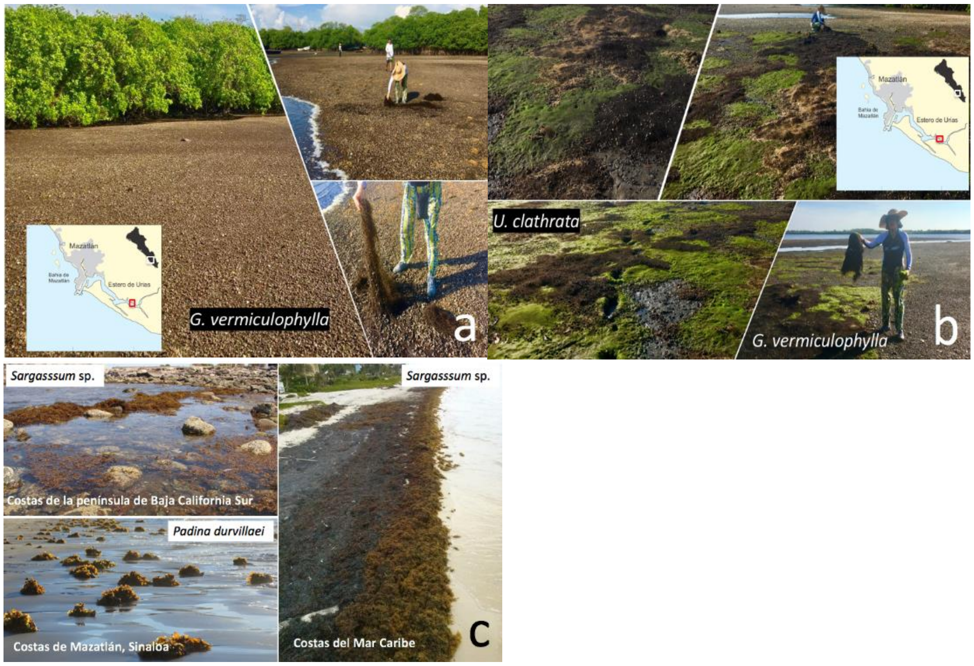

Figure 4. Flowering of the species a) *Gracilaria vermiculophylla* in the Estero de Urias, in Mazatlán, Sinaloa (April, 2017); e) of the species *Ulva clathrata* and *Gracilaria vermiculophylla* in the Estero de Urias, in Mazatlán, Sinaloa (October, 2017); and c) coastal arrival of *Sargassum* sp. on the shores of Bahía Concepción in BCS, *Padina durvillaei* in Playa Norte in Mazatlán, Sinaloa and *Sargassum* sp., on the shores of the Mexican Caribbean (May, 2018).

Flowering and its biomass present important spatial and seasonal changes, related to changes in nutrient concentrations and physicochemical conditions of temperature, salinity and solar irradiation in the waters (Green-Ruiz *et al*., 2009). In turn, the degree of nutrient enrichment presents spatio-temporal variations in response to the magnitude of the discharges that different ecosystems receive (Ochoa-Izaguirre *et al*., 2002; Piñón-Gimate *et al*., 2008). However, not only within the coastal lagoons macroalgal blooms occur, but also sites on the coast of the states of Sinaloa, Sonora and Baja California Sur are included.

For example, the formation of large blooms and uprights of *Padina durvillaei* and *Sargassum* sp., on the coasts of Mazatlan, Sinaloa and the peninsula of Baja California Sur, within the Gulf of California is presented (Figure 4c). According to Godinez-Ortega (2009), there are about 100 species of algae for human or animal consumption that can be exploited in Mexico, representing a production of 250 thousand tons per year. Despite having great exploitation potential, there are few studies conducted in Mexico on the use of macroalgae. Recently, there have been large reports of sargassum in the Mexican Caribbean (Figure 4c), which represent a serious problem for the Riviera Maya not only for aesthetic issues and unpleasant odors of its decomposition, but also for its impact on the economy and biodiversity.

In addition, we have collected information on the chemical composition of macroalgae and their taxonomic, spatial and temporal variations. All the macroalgae studied have a high nutritional quality in terms of amino acids and their mineral content; however, the species *G*. *vermiculophylla*, *U. expansa*, *U. lobata* and *C. amplivesiculatum* have a better chemical composition. The chemical composition of the macroalgae populations studied varied with the sampling season, with a greater accumulation of nutrients in the winter.

Changes in the chemical composition of macroalgae populations in Mexico have been previously reported (Castro-González *et al*., 1996; Peraza-Yee, 2011; 2014; Di Filippo Herrera, 2014). Finally, progress has been made in the development of techniques for the production of biofertilizers from macroalgae, guaranteeing the highest extraction efficiency and the best quality in terms of concentration of beneficial compounds.

Except for technical issues pending refining, the processing of fresh macroalgae requires grinding, acid and alkaline hydrolysis under controlled temperatures and pH regulation, filtration and centrifugation, drying and powder grinding and stabilization of the final product. This allows to obtain products with different presentations and forms of application, including powders, liquids, suspensions and gels.

Impacts of the exploitation of flourishes in the production of biofertilizers

As can be seen, the use of macroalgae to produce biofertilizers is not new, but the use of anthropogenically induced macroalgal blooms. Blooms are more frequent, they extend for longer periods, the area they cover is larger and they appear in more places. The use of biofertilizers produced from macroalgae blooms in coastal lagoons will promote a type of organic and environmentally friendly agriculture, since it not only allows the recycling of nutrients, but also the production of organic food.

The demand for organic products, worldwide and nationally, is increasing and the prospect for the future is that this type of agriculture will be increasingly important. In our proposal, the biofertilizer obtained from macroalgae of natural ecosystems (untreated organic matter), and its application in plant cultivation, allows us to certify that it is an organic crop (biodegradable and beneficial soil product) and that Fruits are organic.

In accordance with the provisions of national and international standards such as EU No. 2092/1 (European Union), USDA/NOP final rule (United States of America) and JAS Japan Agricultural Standards for Organic Agricultural Products (Japan), the biofertilizer meets the standards to be considered organic fertilizer. In addition, the use of such biofertilizers makes it possible to comply with the guidelines for the organic operation of agricultural activities, so that the fruits produced can meet the standards established in the Organic Products Law and hold the 'Organic SAGARPA Mexico' seal.

Conclusions

Society is becoming aware of the environmental impacts that human activities produce on ecosystems and the production of goods and services in a sustainable way. On the other hand, the demand for fruits and foods of organic origin is also increased, the demand for organic fertilizers. The production of biofertilizers; starting from macroalgal blooms, it is a sustainable and economically viable alternative that pays in that direction.

Among the limitations of the use of macroalgae blooms, we can mention: a) the spatio-temporal variations of macroalgal blooms, in relation to species, biomass, and nutritional content, which hinders the production of biofertilizers with standardized characteristics and quality; b) the presence of chemical and microbiological contaminants when the blooms come from sites that present environmental contamination; c) difficulties in the extraction of coastal lagoons; and d) the presence in the market of products of Chinese origin of very low cost but without a guaranteed quality.

Acknowledgments

Financing of the projects UNAM-PAPIIT IN206409, PROFAPI2015/198 and PROMEP/103.5/12/481, to Y. Montaño-Ley, H. Bojorquez-Leyva and a large group of students who have supported us in the field work and laboratory during the past 5 years.

Cited literature

Aguado-Santacruz, G. 2012. Introducción al uso y manejo de los biofertilizantes en la agricultura. INIFAP/SAGARPA. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP)-Campo Experimental Bajío, Celaya, Guanajuato, México. ISBN: 978-607-425-807-3.

Aguirre-Medina, J. F.; Irizar, G. M. B.; Peña, R. M. A; Durán, P. A.; Grajeda, C. O. A. y Cruz, C. F. J. 2009. Micorriza INIFAP^{MR}. Biofertilizante para la agricultura/mejor nutrición/mayor crecimiento de raíz. Hoja desplegable. www.inifap.gob.mx.

Arioli, T.; Mattner, S. W. and Winberg, P. C. 2015. Applications of seaweed extracts in Australian agriculture: past, present and future. J. Appl. Phycol. 27(5):2007-2015.

Barbier, E. B.; Hacker, S. D.; Kennedy, C.; Koch, E. W.; Stier, A. C. and Silliman, B. R. 2012. The value of estuarine and coastal ecosystem services. Ecological monographs. 81(2):169-193.

Calderón-Salazar, J. A. 2017. Privilegia a trasnacionales el TLCAN, desfavorable para el agro mexicano. Gaceta UNAM Núm. 4. 856 http://www.gaceta.unam.mx/20170306/el-tlcan-desfavorable-para-el-agro-mexicano/.

Canales-López, B. 1997. Las algas en la agricultura orgánica. Consejo Editorial del Estado de Coahuila. 323 p.

Canales-López, B. 2000. Enzimas-algas: posibilidades de su uso para estimular la producción agrícola y mejorar los suelos. Terra Latinoam. 17(3):271-276.

Canter, L. W. 2018. Environmental impact of agricultural production activities. CRC Press.

Castellanos-Barriga, L. G.; Santacruz-Ruvalcaba, F.; Hernández-Carmona, G.; Ramírez-Briones, E. and Hernández-Herrera, R. M. 2017. Effect of seaweed liquid extracts from Ulva lactuca on seedling growth of mung bean (*Vigna radiata*). J. Appl. Phycol. 29(5):2479-2488. Doi: 10.1007/s10811-017-1082-x.

Castro-González, M. I.; Pérez-Gil, R.; Pérez-Estrella, S. and Carrillo-Domínguez S. 1996. Chemical composition of the green alga *Ulva lactuca*. Cienc Mar. 22:205-213.

Contreras-Cornejo, H. A.; Macías-Rodríguez, L.; Cortés-Penagos, C. and López-Bucio, J. 2009. Trichoderma virens, a plant benefical fungus, enhances biomass production and promotes lateral root growth through an auxin-dependent mechanism in Arabidopsis. Plant Physiol. 149:1579-1592.

Craigie, J. S. 2011. Seaweed extract stimuli in plant science and agriculture. J. Appl. Phycol. 23(3):371-393.

Di Filippo-Herrera, D. A. 2014. Variación de la composición química y actividad biológica del alga café *Sargassum horridum* (Setchell & NL Gardner, 1924) de la Bahía de La Paz, BCS, México. Tesis doctoral. Instituto Politécnico Nacional (IPN)-Centro Interdisciplinario de Ciencias Marinas).

Du Jardin, P. 2015. Plant biostimulants: definition, concept, main categories and regulation. Sci. Hortic. 196:3-14. 10.1016/j.scienta.2015.09.021.

FAO. 2015. Food and agriculture organization world fertilizer trends and outlook to 2018. Food and Agriculture Organization of The United Nations-Rome, 2015. http://www.fao.org/3/a-i4324e.pdf).

GEOHAB, 2006. Global ecology and oceanography of harmful algal blooms, harmful algal blooms in eutrophic systems. Glibert, P. (Ed.). IOC and SCOR, Paris and Baltimore. 74 p. http://unesdoc.unesco.org/images/0021/002188/218805e.pdf.

Godínez-Ortega, J. L. 2009. Las algas, desconocidas y sub aprovechadas en el país. Gaceta UNAM 4(139):10-16.

Grageda-Cabrera, O. A.; Díaz-Franco, A.; Peña-Cabriales, J. J. y Vera-Nuñez J.A. 2012. Ensayo impacto de los biofertilizantes en la agricultura. Rev. Mex. Cienc. Agríc. 3(6):1261-1274.

Green-Ruiz, C. R.; Alonso-Rodríguez, R.; López-Aguiar, K.; Páez-Osuna, F.; Ramírez-Jauregui, C.; Ramírez-Reséndiz G.; Ruelas-Inzunza J. R.; Ruiz-Fernández A. C.; Soto-Jiménez, M. F. y Tripp-Quezada L. 2009. Atlas de contaminantes: Lagunas Costeras de Sinaloa.

Hernández-Herrera, R. M.; Santacruz-Ruvalcaba, F. and Ruiz-López, M. A. 2014. Effect of liquid seaweed extracts on growth of tomato seedlings (*Solanum lycopersicum* L.). J. Appl. Phycol. 26:619-629. https://doi.org/10.1007/s10811-013-0078-4.

Hernández-Herrera, R. M.; Santacruz-Ruvalcaba, F.; Zañudo-Hernández, J. and Hernández-Carmona, G. 2016. Activity of seaweed extracts and polysaccharide-enriched extracts from *Ulva lactuca* and *Padina gymnospora* as growth promoters of tomato and mung bean plants. J. Appl. Phycol. 28:2549-2556. https://doi.org/10.1007/s10811-015-0781-4.

Hong, D. D.; Hien, H. M. and Son, P. N. 2007. Seaweeds from Vietnam used for functional food, medicine and biofertilizer. J. Appl. Phycol. 19:817-826. https://doi.org/10.1007/s10811-007-9228-x.

Howarth, R. W. 2008. Coastal nitrogen pollution: a review of sources and trends globally and regionally. Harmful Algae. 8(1):14-20.

INEGI. 2017. Instituto Nacional de Estadística y Geografía. Actualización del Marco Censal Agropecuario 2017. http://www.beta.inegi.org.mx/proyectos/agro/amca.

INEGI-SAGARPA. 2014. Encuesta nacional agropecuaria. Información relevante boletín de prensa Núm. 328/1510. Aguascalientes, Ags. 1-2 pp.

Khan, W.; Rayorath U. P.; Subramanian, S.; Jithesh, M. N.; Rayorath P.; Hodges, D. M.; Critchley, A. T.; Craigie, J. S.; Norrie, J. and Prithiviraj, B. 2009. Seaweed extracts as biostimulants of plant growth and development. J. Plant Growth Regul. 28:386-399.

Kim, S. K. 2011. Handbook of marine macroalgae: biotechnology and applied phycology. John Wiley & Sons.

Kurepin, L. V.; Zaman, M. amd Pharis, R. P. 2014. Phytohormonal basis for the plant growth promoting action of naturally occurring biostimulators. J. Sci. Food Agric. 94(9):1715-1722. 10.1002/jsfa.6545.

McHugh, D. J. 2003. A guide to the seaweed industry. FAO fisheries technical paper 441. Rome: Food and Agricultural Organisation of the United Nations.

Ochoa-Izaguirre, M. J. and Soto-Jiménez, M. F. 2013. Evaluation of nitrogen sources in the coastal ecosystem of Urías, Gulf of California, by using stable isotope in macroalgae. Cienc. Marinas. 39(4):413-430.

Ochoa-Izaguirre, M. J. and Soto-Jiménez, M. F. 2015. Variability in nitrogen stable isotope ratios of macroalgae: consequences for the identification of nitrogen sources. J. Phycol. 51:46-65.

Ochoa-Izaguirre, M. J.; Carballo, J. L. and Páez-Osuna, F. 2002 Qualitative changes in macroalgal assemblages under two contrasting climatic conditions in a subtropical estuary. Bot. Marina 45(2):130-138.

Orth, R. J.; Carruthers, T. J.; Dennison, W. C.; Duarte, C. M.; Fourqurean, J. W.; Heck, K. L.; Hughes, A. R.; Kendrick, G. A.; Kenworthy, W. J.; Olyarnik, S. and Short, F. T. 2006. A global crisis for seagrass ecosystems. Bioscience. 56(12):987-996.

Páez-Osuna, F.; Ramírez-Resendiz, G.; Ruiz-Fernández, A. C. y Soto-Jiménez, M. F. 2007. Contaminación de nitrógeno y fósforo en Sinaloa: fuentes, flujos, efectos y opciones de manejo. Serie lagunas Costeras. 304 p.

Página web: http://www.palaubioquim.com.mx. 2018.

Peraza-Yee, M. M. 2011. Contenido de proteínas en macroalgas del Golfo de California. Tesis de Licenciatura. ITMAZ. 79 p.

Peraza-Yee, M. M. 2014. Caracterización química de macroalgas *Ulva expansa*, *Ulva lobata*, *Colpomenia tuberculata*, *Padina durvillei* y *Gracilaria vermiculophylla* recolectadas en el Litoral de Mazatlán (Bahía y Estero De Urías). Tesis Maestría en Ciencias. Posgrado en Ciencias del Mar y Limnología-Univeersidad Autónoma de México (UNAM). 110 p.

Piñon-Gimate, A.; Serviere-Zaragoza, E.; Ochoa-Izaguirre, M. J. and Paez-Osuna, F. 2008. Species composition and seasonal changes in macroalgal blooms in lagoons along the southeastern Gulf of California. Bot. Marina. 51(2):112-123.

Piñón-Gimate, A.; Soto-Jiménez, M. F.; Ochoa-Izaguirre, M. J.; García-Pagés, E. and Páez-Osuna, F. 2009. Macroalgae blooms and d15N in subtropical coastal lagoons from the Southeastern Gulf of California: Discrimination among agricultural, shrimp farm and sewage effluents. Marine Pollution Bulletin. 58 (8):1144-1151.

Secretaría de Fomento Agropecuario. 2018. http://www.sefoa.gob.mx.

Seghetta, M.; Hou, X.; Bastianoni, S.; Bjerre, A. B. and Thomsen, M. 2016. Life cycle assessment of macroalgal biorefinery for the production of ethanol, proteins and fertilizers -A step towards a regenerative bioeconomy. J. Cleaner Production. 137:1158-1169.

Soto-Jiménez, M. F.; Paez-Osuna, F. and Bojorquez-Leyva, H. 2003a. Nutrient cycling at the sediment-water interface and sediments at Chiricahueto marsh: a subtropical ecosystem associated with agricultural land uses. Water Res. 37:719-728.

Soto-Jiménez, M. F.; Páez-Osuna, F. and Ruiz-Fernández, A. C. 2003b. Organic matter and nutrients in an altered subtropical marsh system, Chiricahueto, NW México. Environ. Geol. 43:913-921.

Teichberg, M.; Fox S. E.; Olsen, Y.; Valiela I.; Martinetto, P.; Iribarne, O.; Yuriko-Muto, E.; Petti, M. A. V.; Corbisier, T. N.; Soto-Jiménez, M. F.; Páez-Osuna, F.; Castro, P.; Freitas, H.; Zitelli, A.; Cardinaletti, M. and Tagliapietra, D. 2010. Eutrophication and macroalgal blooms in temperate and tropical coastal waters: nutrient enrichment experiments with Ulva spp. Global Change Biol. 16(9):2624-2637.

Thirumaran, G.; Arumugam, M.; Arumugam, R. and Anantharaman, P. 2009. Effect of seaweed liquid fertilizer on growth and pigment concentration of abelmoschus esculentus (I) medikus. American-Eurasian J. Agron. 2(2):57-66.

Valiela, I.; McClelland, J.; Hauxwell, J.; Behr, P. J.; Hersh, D. and Foreman, K. 1997. Macroalgal blooms in shallow estuaries: controls and ecophysiological and ecosystem consequences. Limnology and Oceanography. 42(5 II):1105-1118.

Wijesekara, I.; Pangestuti, R. and Kim, S. K. 2011. Biological activities and potential health benefits of sulfated polysaccharides derived from marine salgae. Carbohydrate Polymers. 84(1):14-21.

Zemke-White, W. L. and Ohno, M. 1999. World seaweed utilisation: an end-of-century summary. J. Appl. Phycol. 11(4):369-376. 10.1023/A:1008197610793.

Zermeño-González, A. 2015. Biofertilización de vid en relación con fotosíntesis, rendimiento y calidad de frutos. Agrociencia. 49(8):875-887.